THERMAL & FLUIDS ANALYSIS WORKSHOP

GSFC· 2015

Investigation on the Practicality of Developing Reduced Thermal Models

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Introduction

- Why thermal models?
  - To simulate on-orbit thermal response of spacecraft
- Why reduced models?
  - Reduce runtime from detailed models
  - Quick analysis turnaround
- Expected outcome
  - Decreased runtime
  - Loss in accuracy
- Does the decreased runtime to obtain results compensate for the additional effort placed on producing the reduced models?

Detailed vs. Reduced

- Detailed model
  - A thermal model developed with the intention of fully capturing the thermal responses of the spacecraft in is on-orbit environment
- Reduced model
  - Simplified thermal model (less nodes and surfaces) produced with the intention of reducing simulation runtime

Methodology

- Hardware Specifications:
  - Processor: Intel Core i7 vPro, 3.7 GHz
  - System: 64-bit OS
  - Ram: 8.0 GB

- Current work focuses on:
  - Comparison of runtime vs. nodal reduction between reduced and detailed models across projects
  - Comparison of nodal reduction vs. accuracy across six major components of each spacecraft/instrument pair

Methodology

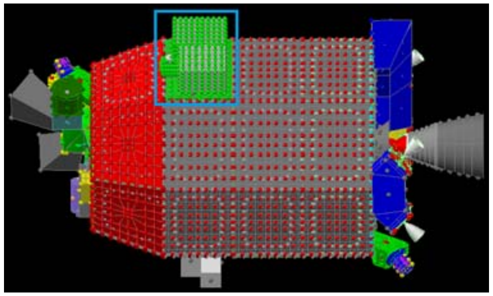
1. Set up Case Set in Thermal Desktop (TD)

    - Set up cases with both the spacecraft reduced and detailed instrument models on the spacecraft bus. When possible, integrate the spacecraft detailed/reduced model to the bus to obtain the total observatory-level model runtime
    - Calculate environmental heat due to spacecraft orbit (heat rate)
    - Specify duration of transient run (5 orbits)
    - Conduct ray trace calculations for radiation couplings (radks)
2. Start case set in TD to generate SINDA .inp file
3. Open SINDA/FLUINT and run .inp file
    - Record start and end times to solve case
4. Repeat each TD case set run three times to obtain an average runtime
    - Calculate total run time for each SINDA run (runtime = end - start time)
5. Post-process using TARP
    - Generate Temperature tables
    - Incorporate Weighting file to mitigate effect of components with low thermal masses (e.g. MLI blankets)
6. Compare Reduced model data with Detailed model data
    - Record change in temperature (delta T = reduced - detailed model temperature results)

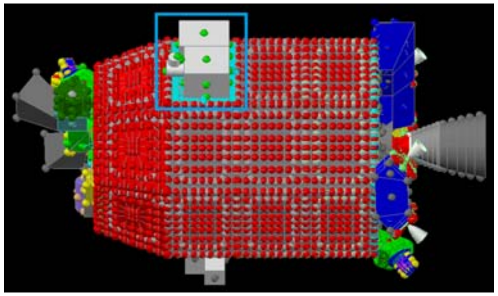
Lunar Atmosphere and Dust Environment Explorer (LADEE)

- Launch Date: September 2013
- Mission: Analyze the Moon's thin exosphere and the lunar dust environment
- Investigation Focus:
  Neutral Mass Spectrometer (NMS)
  - NMS instrument measures variations in chemistry of the lunar atmosphere at different altitudes and orbits
- Bus with reduced instrument models used as baseline
  - NMS detailed model incorporated into reduced bus model

NMS Reduced vs. Detailed Model Analysis



Detailed Thermal Model
(NMS instrument in blue box)



Reduced Thermal Model
(NMS instrument in blue box)

- Reduced Model Development Time: 80 hr
- Nodal Count
  - Spacecraft: 14,750
  - Detailed NMS: 1,040
  - Reduced NMS: 35

NMS Nodal Reduction: 6.8%

Case	Complexity	Time (min)	Time Reduction
Hot	Detailed	57	12 min
	Reduced	45	
Cold	Detailed	61.7	8.7 min
	Reduced	53	

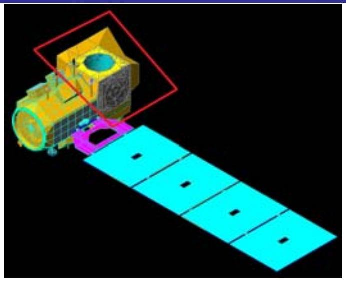
LADEE - Hot Case			
Sub Model	Temperature [°C]		
	Detailed	Reduced	Δ T
BSPL	37.4	-16.1	-53.5
CPNL	-21.3	-21.3	0.0
INTP	12.9	3.8	-9.1
MEB	-42.7	-21.9	20.8
QMS	14.9	-27.0	-41.9

LADEE - Cold Case			
Sub Model	Temperature [°C]		
	Detailed	Reduced	Δ T
BSPL	-23.9	-19.5	4.4
CPNL	-45.3	-22.4	22.9
INTP	10.1	10.8	0.7
MEB	-61.9	-22.8	39.1
QMS	-29.3	-30.2	-0.9

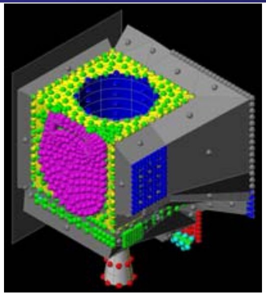
Ice, Cloud, and Land Elevation Satellite 2 (ICESat-2)

- Launch Date: 2017
- Mission: Measure ice cap elevation and thickness
- Investigation Focus:
  Advanced Topographic Laser Altimeter System (ATLAS)
- ICESat-2 bus integrated with reduced ATLAS model
  - Due to difficulty integrating detailed ATLAS with bus model, independently ran both reduced and detailed ATLAS models and compared with the total runtime for integrated ICESat-2 bus

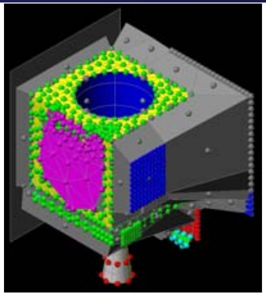
ATLAS Reduced vs. Detailed Model Analysis



Full ICESat-2
Thermal Model
(ATLAS in red box)



ATLAS
Detailed
Thermal Model



ATLAS
Reduced
Thermal Model

- Reduced Model Development Time: 120 hr
- Nodal Count
  - Detailed ATLAS: 11,737
  - Reduced ATLAS: 6,392

ATLAS Nodal Reduction: 45.5%

Case	Complexity	Time (min)	Time Reduction
Hot	Detailed	80	65.7 min
	Reduced	14.3	
Cold	Detailed	36.75	30.25 min
	Reduced	6.5	

ATLAS - Hot Case

Sub Model	Temperature [°C]		
	Detailed	Reduced	Δ T
LRS_ORAD	13.9	13.9	0
LTCS_RAD	-15.6	-16.2	-0.6
MEB_RAD	25.9	26.1	0.2
PBC	19.9	20.2	0.3
PDU_RAD	23.7	23.6	-0.1
STARTPD	25.2	23.4	-1.8

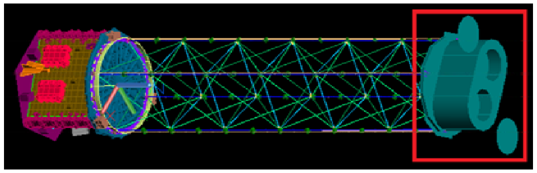
ATLAS - Cold Case

Submodel	Temperature [°C]		
	Detailed	Reduced	Δ T
LRS_ORAD	20.7	20.9	0.2
LTCS_RAD	-48.0	-48.9	-0.9
MEB_RAD	5.6	5.8	0.2
PBC	0.4	0.6	0.2
PDU_RAD	-12.0	-12.0	0
STARTPD	4.7	4.0	-0.7

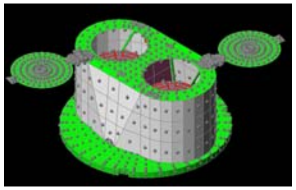
Gravity and Extreme Magnetism Small Explorer (GEMS)

- Launch Date: CANCELLED
- Mission: Observe strong gravitational fields around black holes and magnetic fields around pulsars
- Investigation Focus: Mirror Optical Bench (MOB)
  - Contains two mirror assemblies which detect x-rays with energies between 2,000 and 10,000 eV
- GEMS bus integrated with reduced MOB model
  - Due to difficulty integrating detailed MOB with bus model, independently ran both reduced and detailed mirror models and compared with the total runtime for GEMS bus with reduced MOB model

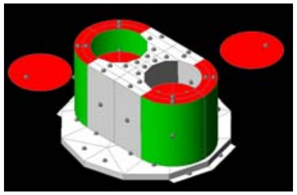
MOB Reduced vs. Detailed Model Analysis



Full GEMS Thermal Model (Mirror in red box)



Mirror Detailed Thermal Model



Mirror Reduced Thermal Model

- Reduced Model Development Time: 80 hr
- Nodal Count
  - Detailed Mirror: 17,025
  - Reduced Mirror: 654

Mirror Nodal Reduction: 96.2%

Case	Complexity	Time (min)	Time Reduction
Hot	Detailed	444.3	129.3 min
	Reduced	315	
Cold	Detailed	416.3	136 min
	Reduced	280.3	

GEMS - Hot Case

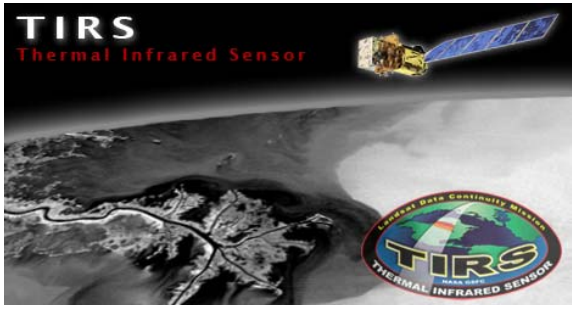
Submodel	Temperature [°C]		
	Detailed	Reduced	Δ T
MOBDECK	-56.8	-57.6	-0.8
PMIRR1	-61.6	-45.5	16.1
PMIRR2	-61.8	-45.9	15.9
SS_DECK	-56.6	-52.6	4.0
TOP_TS_1	-60.4	-44.3	16.1
TOP_TS_2	-60.7	-44.7	16.0

GEMS - Cold Case

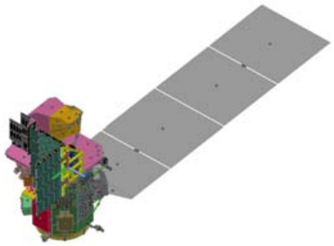
Submodel	Temperature [°C]		
	Detailed	Reduced	Δ T
MOBDECK	-74.0	-75.0	-1.0
PMIRR1	-80.9	-79.0	1.9
PMIRR2	-79.2	-69.9	9.3
SS_DECK	-82.1	-80.1	2.0
TOP_TS_1	-81.2	-80.3	0.9
TOP_TS_2	-79.4	-71.9	7.5

Landsat 8

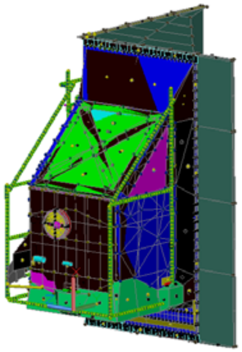
- Launch Date: February 11, 2013
- Mission: Measure land surface temperature in two thermal bands with a new technology that applies quantum physics to detect heat
- Investigation Focus:
  Thermal Infrared Sensor (TIRS)
- Comparison between reduced TIRS integrated on bus vs. detailed TIRS integrated on bus



TIRS Reduced vs. Detailed Model Analysis



Full Landsat Thermal Model



TIRS Detailed Thermal Model

TIRS Reduced Thermal Model

- Reduced Model Development Time: N/A
- Nodal Count
  - Spacecraft: 1,415
  - Detailed TIRS: 18,529
  - Reduced TIRS: 1,556

TIRS Nodal Reduction: 91.6%

Case	Complexity	Time (min)	Time Reduction
Hot	Detailed	31.7	-4.2 min
	Reduced	35.9	
Cold	Detailed	47.5	16.4 min
	Reduced	31.1	

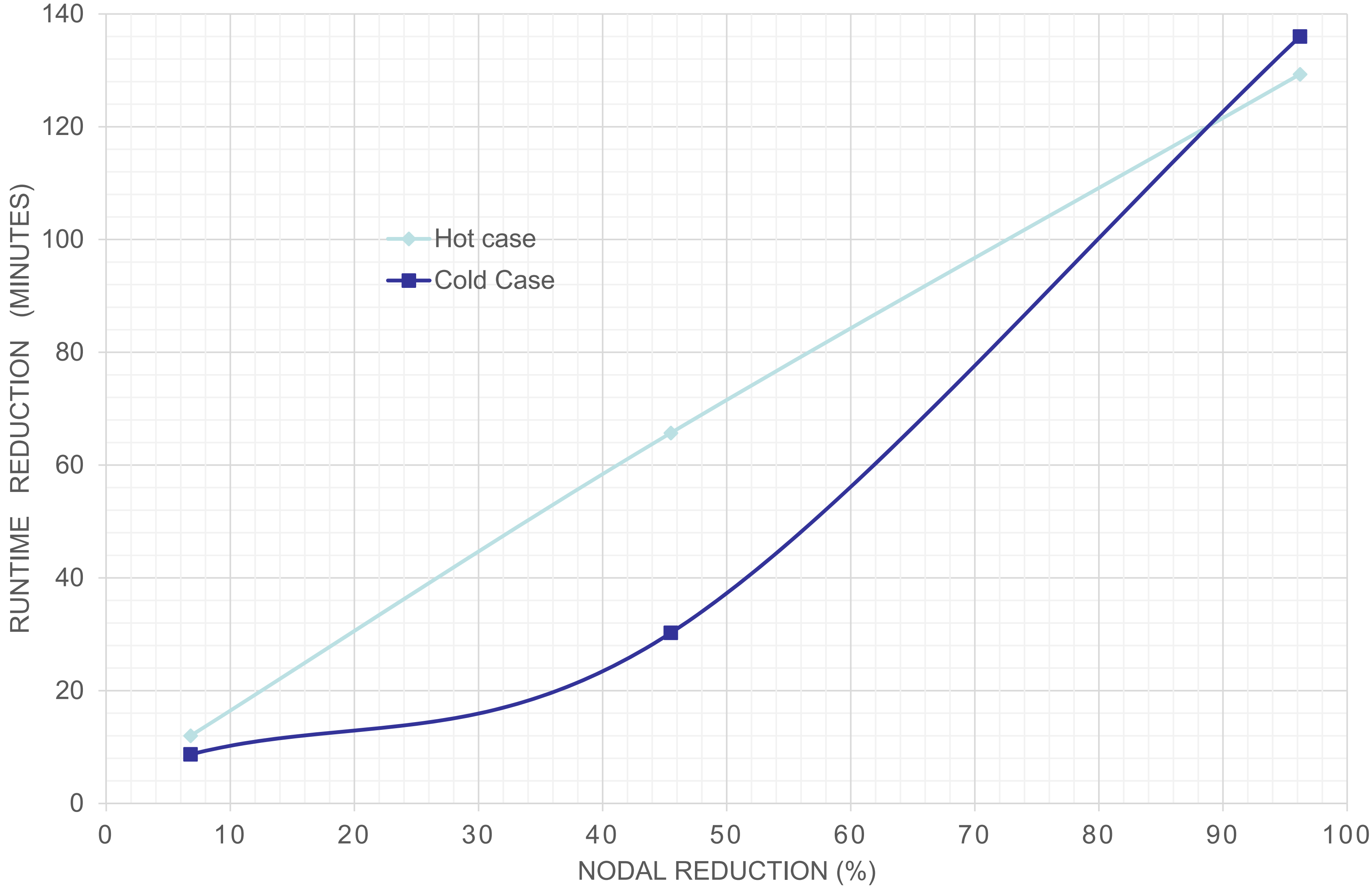
TIRS - Hot Case

Submodel	Temperature [°C]		
	Detailed	Reduced	Δ T
STAGE 1	-84.3	-84.0	0.3
STAGE 2	-85.5	-85.4	0.1
STAGE 3	-86.8	-86.8	0.0
SSM	2.4	-1.9	0.5
BBCAL	44.1	44.9	-0.8
FPE	9.0	9.5	-0.5

TIRS - Cold Case

Submodel	Temperature [°C]		
	Detailed	Reduced	Δ T
STAGE 1	-84.6	-84	0.6
STAGE 2	-85.7	-85.4	0.3
STAGE 3	-86.9	-86.8	0.1
SSM	-13.3	-16	-2.7
BBCAL	-3.6	-3.8	-0.2
FPE	7.4	8.9	-1.5

Effects of Nodal Reduction on Runtime



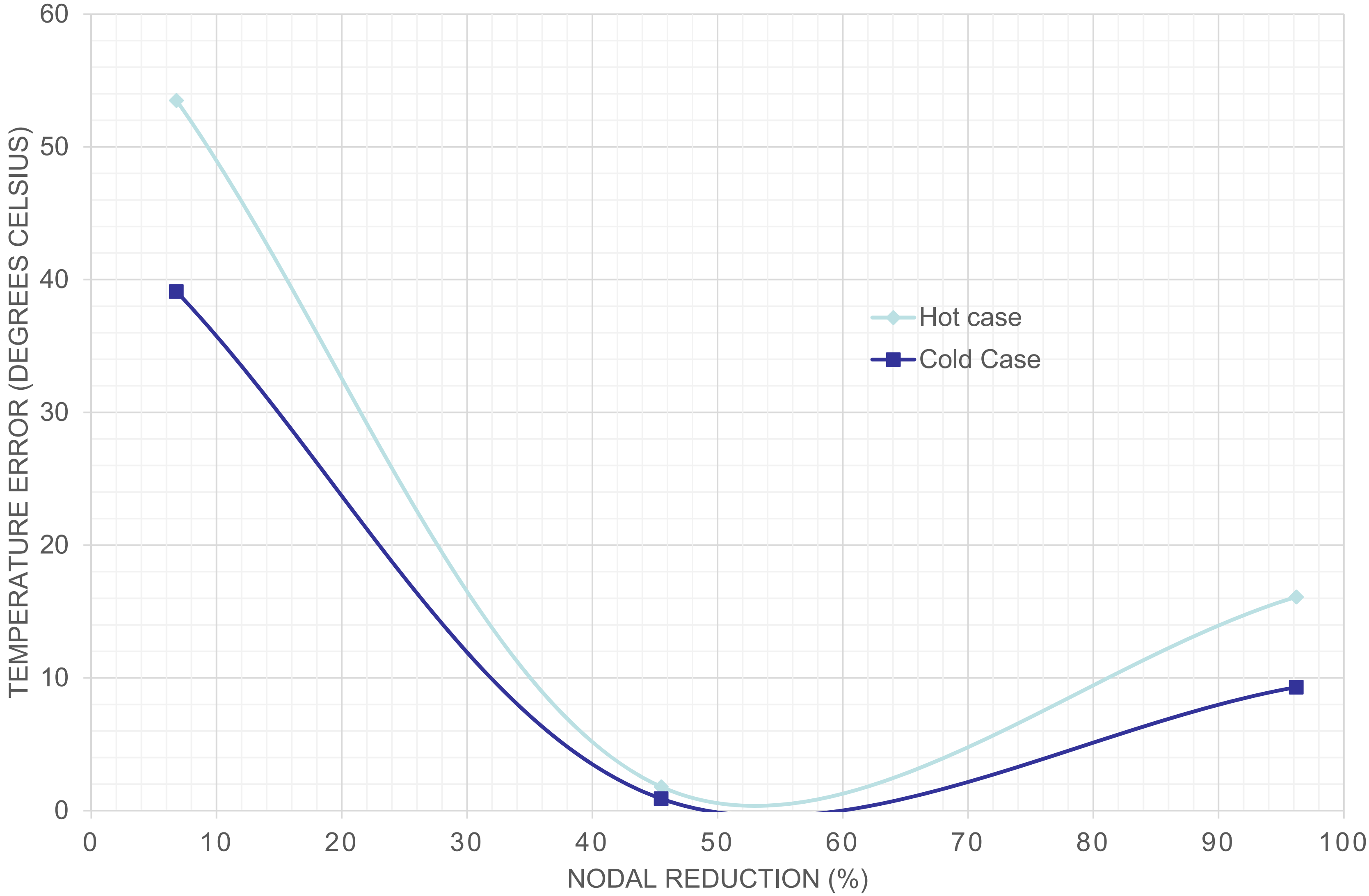
Break-Even Analysis

- Definition: Number of reduced model simulation runs needed to match the development time
- Objective: Justify development time
- Compiling known data:

Mission	Development Time (hours)	Hot Case Time Reduction (minutes)	Cold Case Time Reduction (minutes)
GEMS	80	129.3	136
ICESAT-2	120	65.7	30.25
LADEE	80	12	8.7
Landsat 8	1000	-4.2	16.4

Break Even Run Count		
Mission	**Hot**	**Cold**
GEMS	38	36
ICESAT-2	110	239
LADEE	400	552
Landsat 8	--	3659

Effects of Nodal Reduction on Data Accuracy



Accuracy Loss

- Accuracy loss obtained across all reduced models. Maximum ΔT for each:

Mission	Hot	Cold
LADEE	53.5	39.1
ICESat-2	1.8	0.9
GEMS	16.1	9.3
Landsat 8	0.8	2.7

- Larger error (delta T) in Hot cases
  - Greater fluctuations due to heat loads
- No trend established
  - No correlation between nodal reduction and accuracy loss

Observations from Analysis Results

- Runtime for hot cases generally greater than cold cases
  - Possible cause is greater amount of incident environmental flux in hot case, causing greater inputs to energy balance equation
  - However, some models have slower cold case runtime: this could be due to longer time needed to resolve heater power
- TIRS detailed hot case runtime actually shorter than reduced model runtime despite having 671% more nodes
  - Perhaps numerical instability in reduced model led to slower runtime
  - Since computer hardware used for solving these cases had large amounts of memory, this could also be due to greater capacity of computer to iteratively solve energy balance per timestep, regardless of matrix size passed in
- Overall not a linear reduction between runtime and nodal count

Conclusion

- Given break-even analysis, development of reduced models are justified only if reduced model sees intensive use
  - With increasing computer power, the difference in runtime may not justify time needed for development of reduced model
- Time savings on runtime increase with nodal reduction
- No clear correlation between accuracy and nodal reduction
  - Highly dependent on quality of reduced model developed

Recommendations

- Improve book-keeping of model development
  - Record development time
  - Provide compatible models
- Use computer dedicated to running simulations
  - Avoid using same computer during simulations
- Select a more representative pool of reduced models
  - Varying levels of model reduction
  - Define the established runtime reduction trend
- Consistency in Model Production